LSST Sensor Characterization with Ultraflats

Michael Baumer and Aaron Roodman

SLAC NATIONAL ACCELERATOR LABORATORY

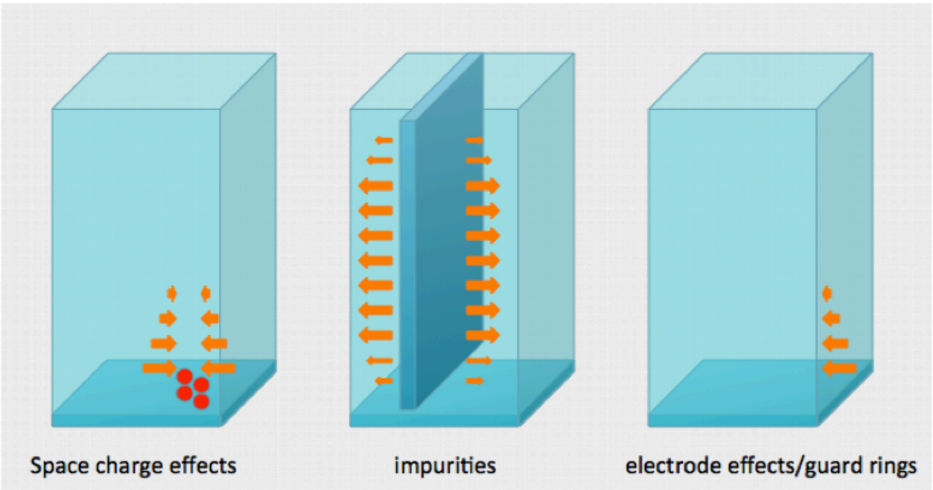
Stanford

KIPAC

Introduction

With the great promise of LSST science come unprecedented demands on camera performance—sub-percent photometry and ellipticities good to a few parts in a thousand. These demands make it necessary to investigate heretofore unconsidered sources of systematic errors within the LSST camera.

One possible source of these errors comes from small-scale variations in pixel sensitivity, classically referred to as pixel response non-uniformity (PRNU). It has previously been assumed that the dominant contribution to PRNU comes from **local variation in the quantum efficiency (QE)** of a pixel within a CCD sensor. However, more recent work [1,2] has indicated that **lateral electric fields** produced by impurities within the silicon bulk of a CCD can also contribute to PRNU.

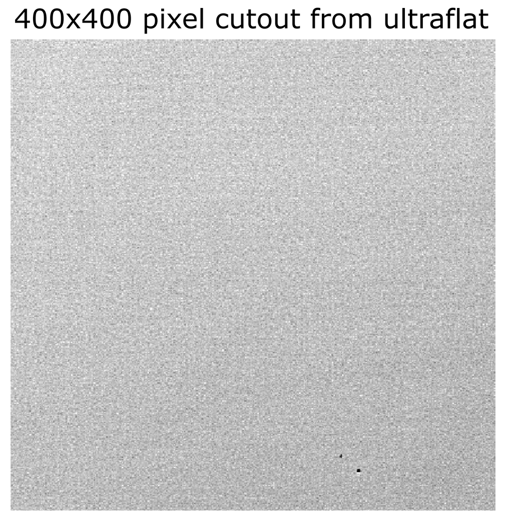


from Stubbs 2014

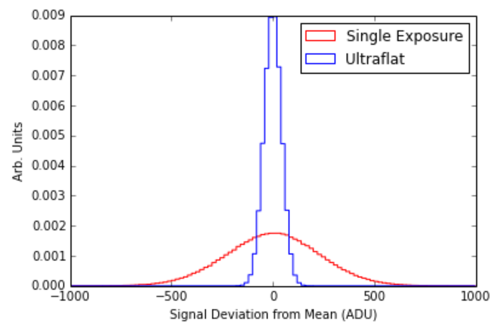
To investigate these effects in an e2v-250 LSST prototype sensor (112-03), we constructed "ultraflat" images by combining 500 flat-field exposures at four different light levels taken by the Harvard sensor testing lab.

Shot noise contamination decreases with number of coadded images as expected, but **what are the causes of the residual variance (PRNU)?**

400x400 pixel cutout from ultraflat

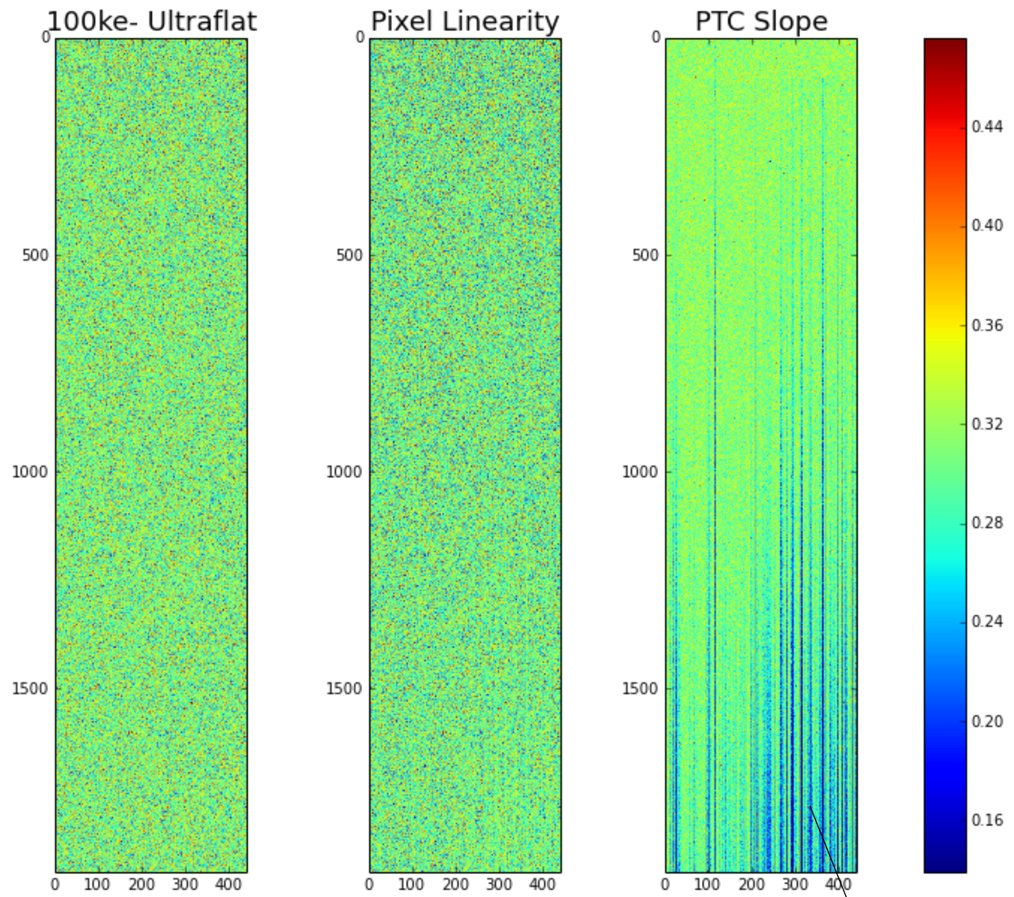


Light Level (e^-)	Residual Shot Noise
25,000	.11 %
75,000	.04 %
100,000	.03 %
125,000	.02 %

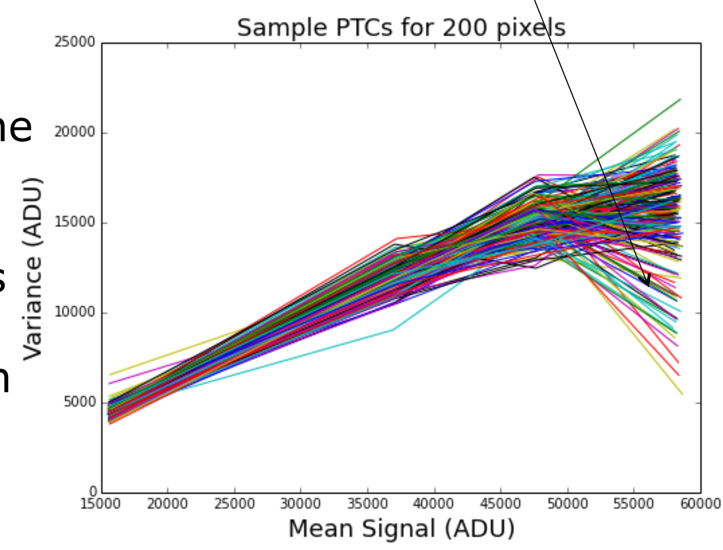


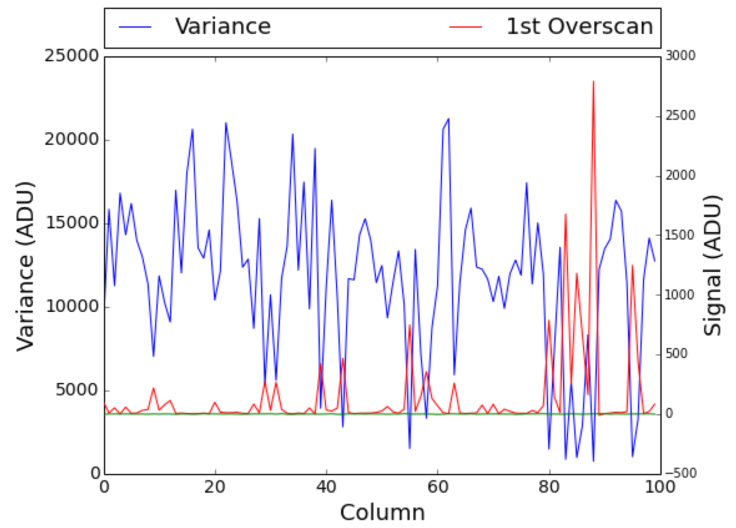
Single-pixel Photon Transfer

Photon transfer curves (PTCs) are commonly used to characterize the performance of CCDs. With ultraflats, we can perform a linearity (signal vs. time) and PTC (variance vs. signal) analysis on a pixel-by-pixel basis:



Though no patterns are discernible in the raw ultraflat or linearity map, certain columns exhibit lower variance at high light level (but still below full-well).



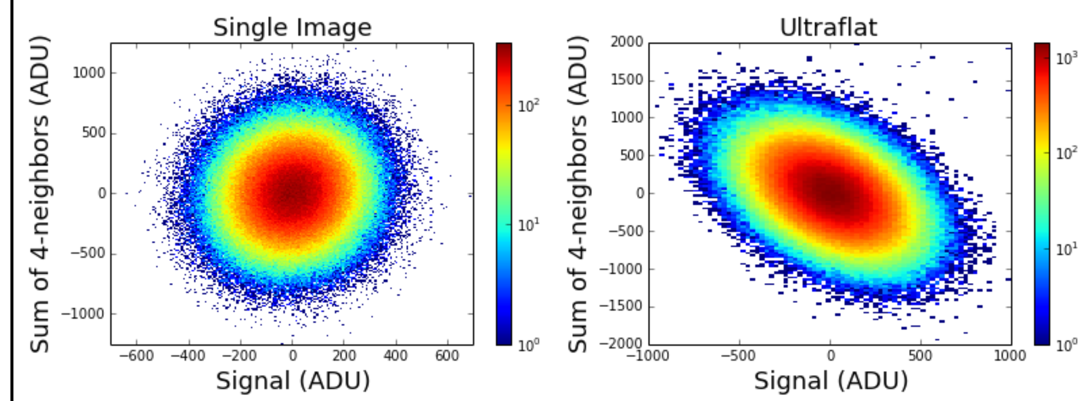


Missing variance is associated with unexpected charge in first overscan row.

One possible explanation is a flux-dependent charge transfer inefficiency, but what would be the physical mechanism? Why is the effect localized to particular columns?

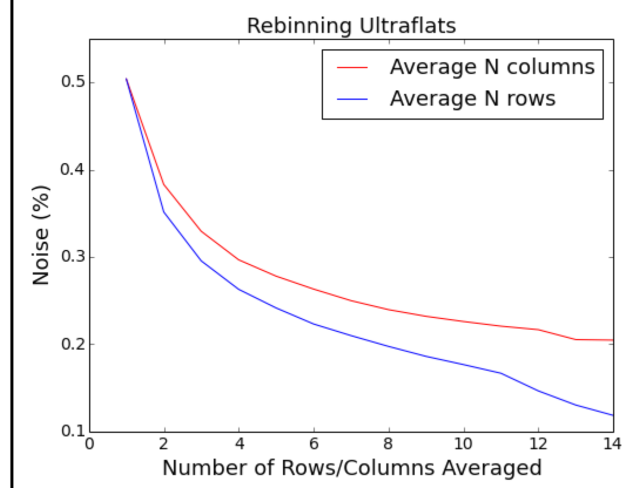
Pixel Size Variation

By comparing each pixel's value to the sum of its 4-neighbors, we can probe both intrinsic pixel size variation and the brighter-fatter effect.



+8% correlation: brighter-fatter effect

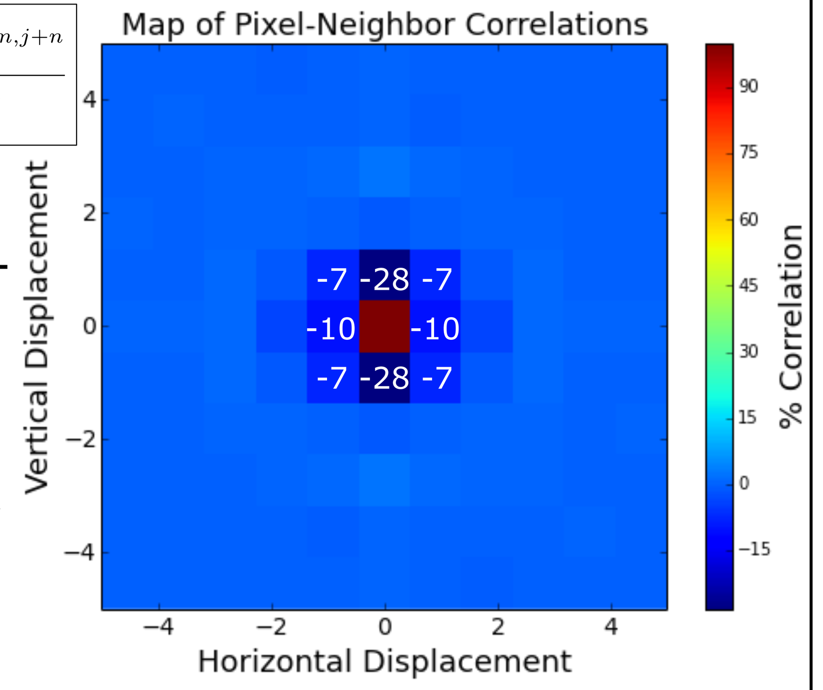
-33% correlation: pixel-size variation



Loss of variance with rebinning consistent with pixel size variation: noise "washes out" on multi-pixel scales.

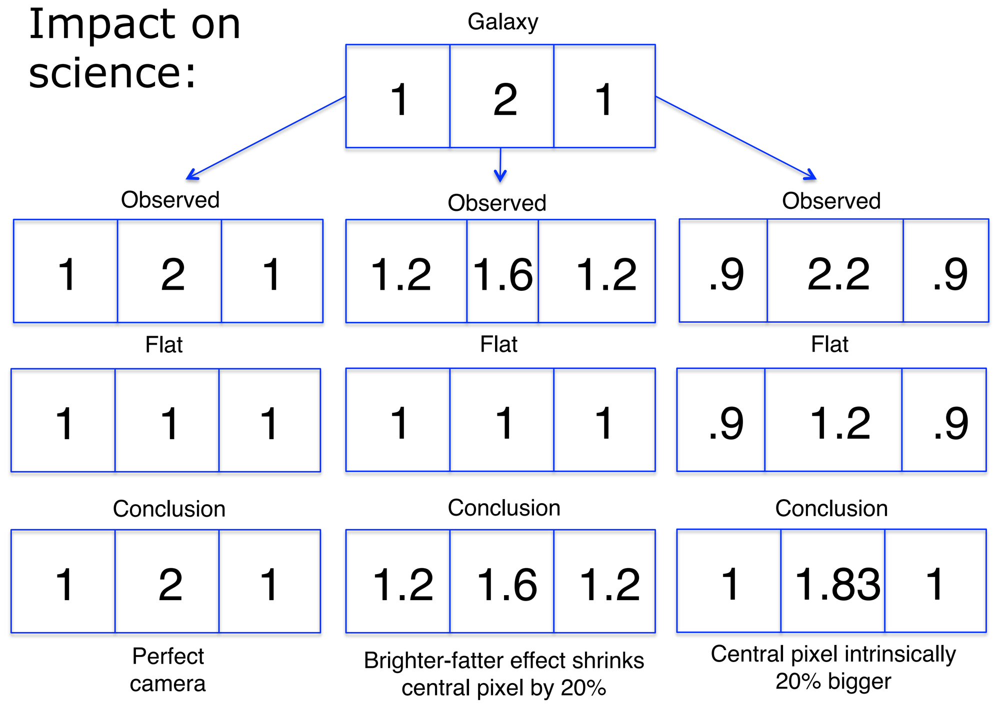
$$C_{m,n} = \frac{\sum_{i,j} N_{i,j} N_{i+m,j+n}}{\sum_{i,j} N_{i,j}^2}$$

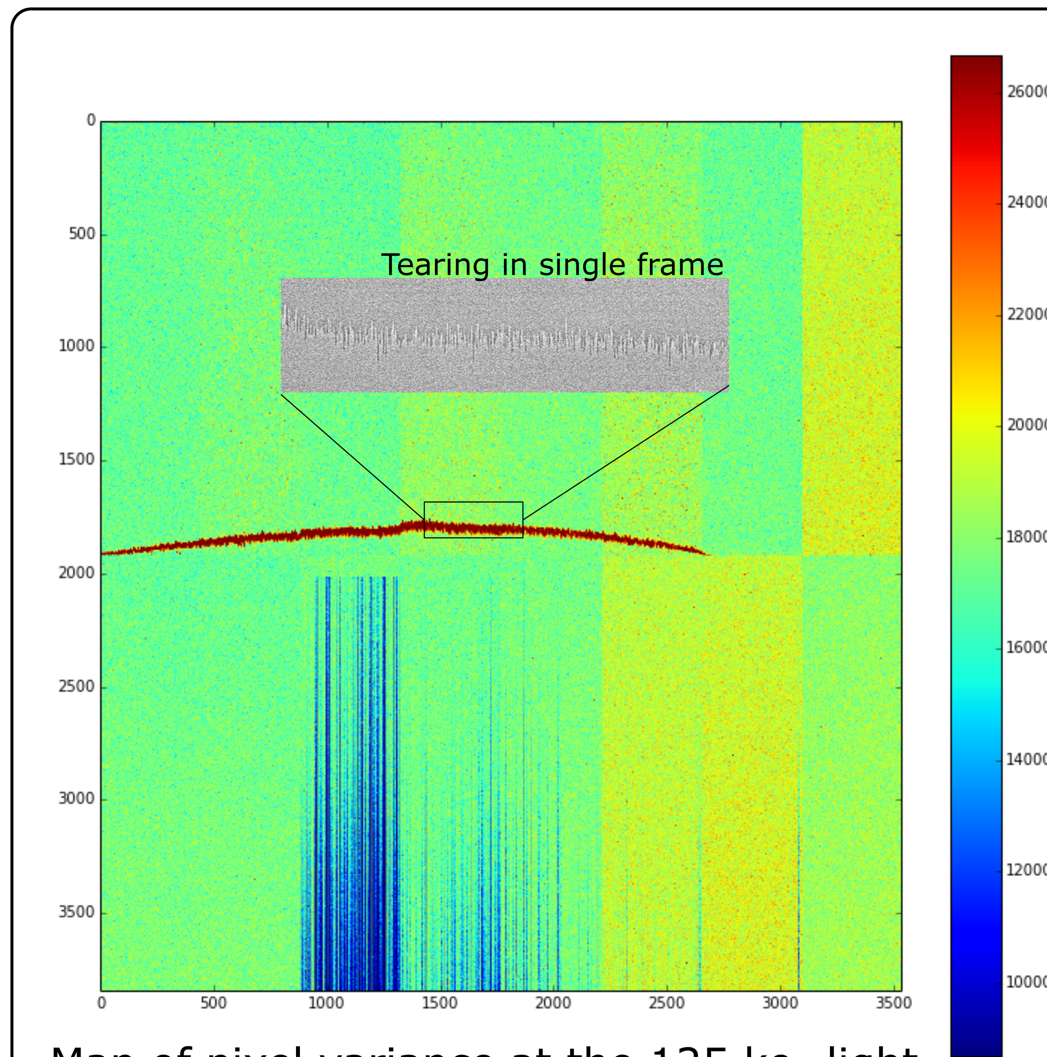
from Smith 2008



Map of pixel-neighbor correlations illustrates asymmetry in sensitivity variations.

Impact on science:





Map of pixel variance at the 125 ke- light level: the effect of "tearing" is visible.

Conclusions and Future Work

Ultraflats are useful probes of pixel geometry in CCD sensors. We have used them here to probe linearity, noise, and sensitivity properties at pixel-level scale, and have observed apparent variations in pixel size in an LSST prototype sensor. Efforts to create a model for these effects (which would allow full decoupling of PRNU contributions from pixel size variation and local QE variation) are ongoing, with the goal of improving the procedure of naïve flat-fielding. We also plan to take images sinusoidal illumination fields, which have the potential to allow improved characterization of pixel size variation in our test device.

Acknowledgments + References

[1] Stubbs 2014 JINST 9: C3032
[2] Smith 2008 SPIE Conf. Ser. 7021

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